A NOTE ON THE TEMPERATURE TREND, 1815–1963, AS REVEALED BY THE CLOSING DATES OF NAVIGATION ON LAKE CHAMPLAIN

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It has been recognized that a warming trend in the North Atlantic Basin started near the end of the 19th century. As a contribution to the study of this climatic trend we decided to analyze the "closing dates" [1] for Lake Champlain (fig. 1), after the methods of H. Arakawa [2], A. V. Havens [3], and P. H. Kutschenreuter [4]. We felt that the use of "closing dates," rather than conventional temperature data, would better show the macroclimatic changes and would minimize the chance of error brought about by changes of exposure, instrumentation, and observational technique. Also, the date on which a body of water the size of Lake Champlain freezes over between Burlington, Vt., and Port Douglas, N.Y., is a function of many, rather than just a few days of subfreezing temperatures, and is, therefore, a fairly good indicator of the severity of the winter up to that time.

Closing dates for Burlington to Port Douglas navigation are given in chronological order in [1] for the period beginning with the winter of 1815–16 up to and including the winter of 1953–54. The data for the seasons 1954–55 through 1962–63 (table 1) are taken from the records of the Weather Bureau Airport Station, Burlington, Vt. For the full period, 148 years, there are two winters missing (1829–30 and 1830–31), and 13 "open" winters (table 2), in which the Lake did not freeze over between the two ports.

Our first step was to estimate the mean closing date ($\overline{X}$) and standard deviation (S) for the full period, less of course the two missing winters and the 13 open winters. We found $\overline{X}=33.45$ (approximately February 2), with an $S=14.05$. We then performed a "runs test" [5] on the entire period, the result of which indicated a trend toward later closing dates, but did not give conclusive evidence of the trend.

TABLE 1.—*Dates of closing of navigation, Burlington to Port Douglas Lake Champlain, 1954–1963.*

Season	Closing Date
1954–1955	Feb. 9.
1955–1956	open.
1956–1957	open.
1957–1958	Feb. 12.
1958–1959	Feb. 9.
1959–1960	open.
1960–1961	Jan. 27.
1961–1962	Feb. 16.
1962–1963	Feb. 8.

With the suggestion of a trend we divided the period 1815–16 to 1962–63, into two sub-periods of approximately equal length. For the first period, 1815–16 to 1889–90, $\overline{X}_1=29.29$ (approximately January 29) and $S_1=11.81$, while for the second period, 1890–91 to 1962–63, $\overline{X}_2=38.05$ (approximately February 7) and $S_2=14.47$. Next we plotted the cumulative frequency of the closing dates for the entire period on probability paper, and found that the last 20 values of the plot are above those expected of a normal distribution (straight line). Fifteen of these "late" dates occurred during the second half of the period (fig. 2).

In order to justify splitting the full period into two sub-periods, we made a z test [6] and a t test [7]. Comparing the mean dates of each of the sub-periods with the mean dates for the full period, we found the difference with respect to both $\overline{X}_1$ and $\overline{X}_2$ was significant at the 0.01 level. The t test of $\overline{X}_1$ against $\overline{X}_2$ gave a similar result. From this we concluded that the difference in mean

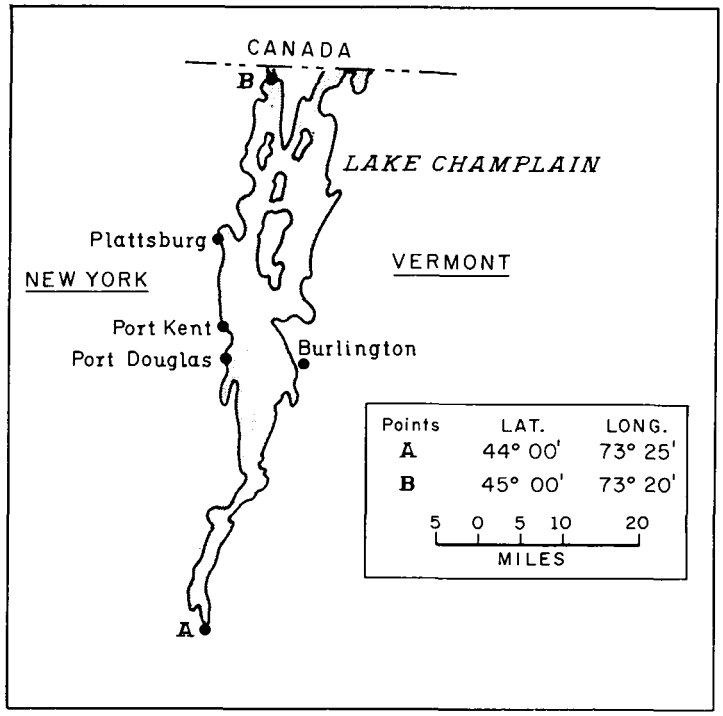

FIGURE 1.—Lake Champlain.

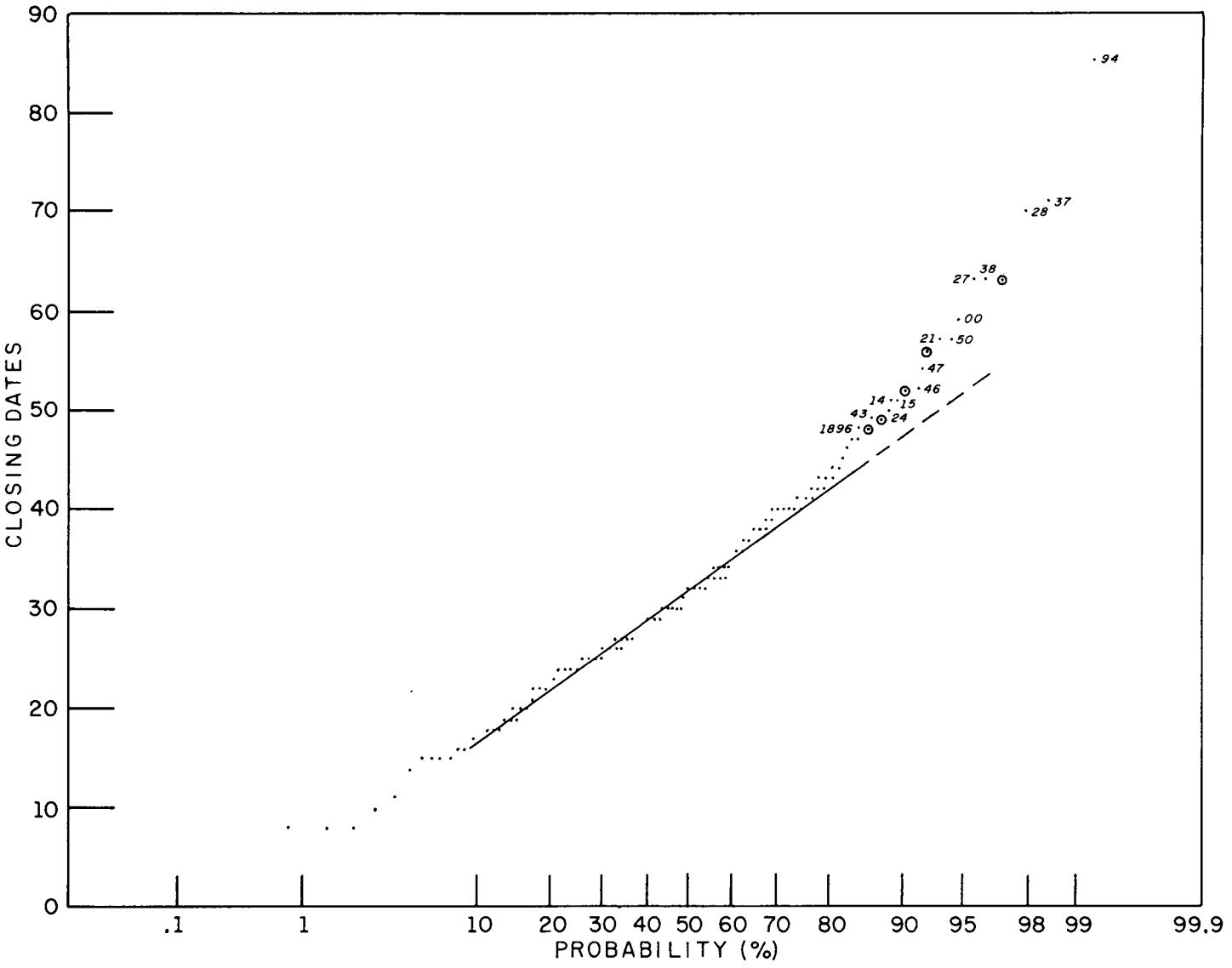

FIGURE 2.—Cumulative frequency of "closing dates" for entire period 1815–1963. Numbers are last two digits of last year of season (in 1900's unless otherwise specified); for example, 02=1901–02. Circled dot indicates first sub-period.

closing dates between the two sub-periods (8.76 or 9 days) was not due to chance, and that splitting the record at 1890 was justified because a change in the temperature regime did take place between the two sub-periods. This change toward later "closing dates" of course agrees with the generally established warming trend that began in the late 19th century.

TABLE 2.—*List of "open" winters during which Lake Champlain did not freeze over between Burlington and Port Douglas*

1827–1828	1951–1952
1841–1842	1952–1953
1849–1850	1953–1954
1918–1919	1955–1956
1931–1932	1956–1957
1932–1933	1959–1960
1948–1949	

A test for the entire period was similarly applied to the probability of "open" winters (winters during which Lake Champlain did not freeze over). This more rigid test shows that, compared to the probability for the full period, the lower probability of an open winter during the first sub-period is significant at the 20 percent level. The higher probability of an open winter during the second sub-period, compared to the probability for the full period, is significant at the 28 percent level.

From purely climatological considerations, one should expect that the statistical significance of open winters at Lake Champlain (0.04 level for sub-period one vs. sub-period two) would be less than that for the later closing dates (>0.01), barring extraneous influences. In Kutschenreuter's words, "A later freezing date is an indication of somewhat higher mean water temperature

during the early part of the winter, whereas an open winter is indicative of mean surface water temperatures of 32° F. or higher during the entire winter. An open winter is indicative of an entire winter with temperatures averaging considerably above the normal and hence a more rare event than simply a warmer early winter period, as indicated by a later freezing date."

The preponderence of "open" winter reports in recent years might be attributed to the increased use of aircraft reporting, but since it also fits into the warming trend we feel that a real change has come about.

ACKNOWLEDGMENT

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